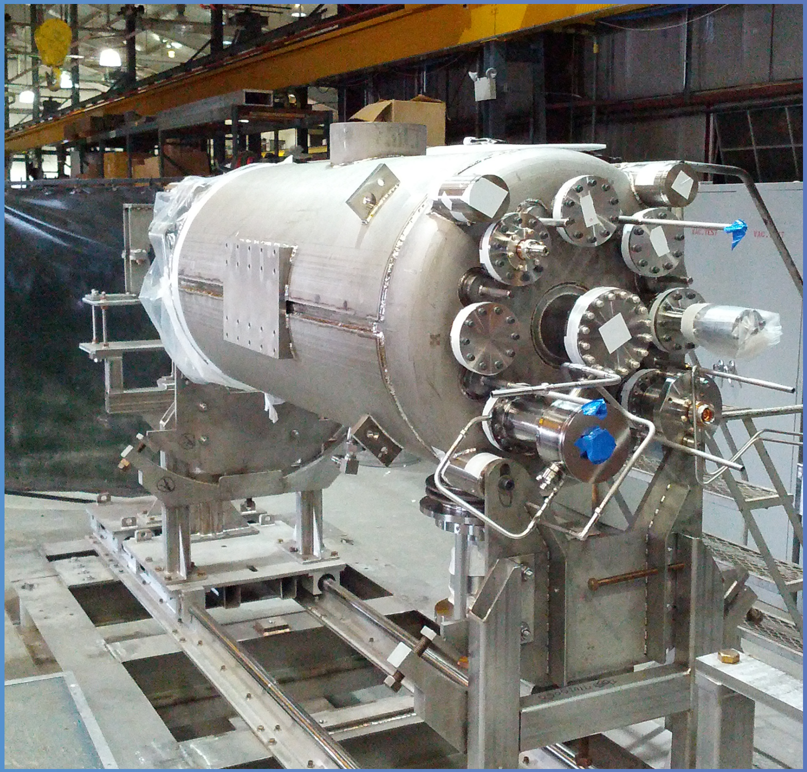
56 MHz SRF cavity:
assembly status and commissioning plans



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On behalf of the 56 MHz team

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BROOKHAVEN NATIONAL LABORATORY

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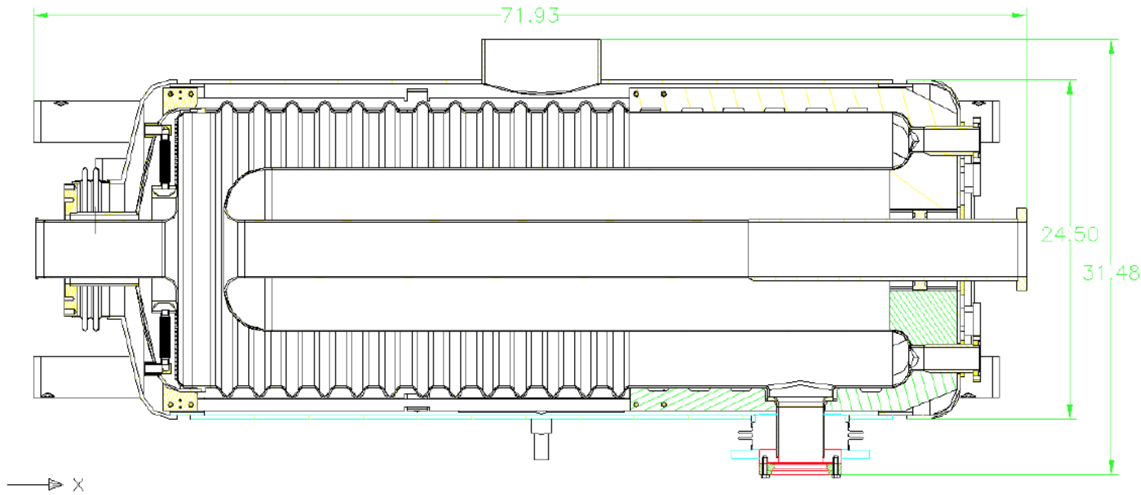
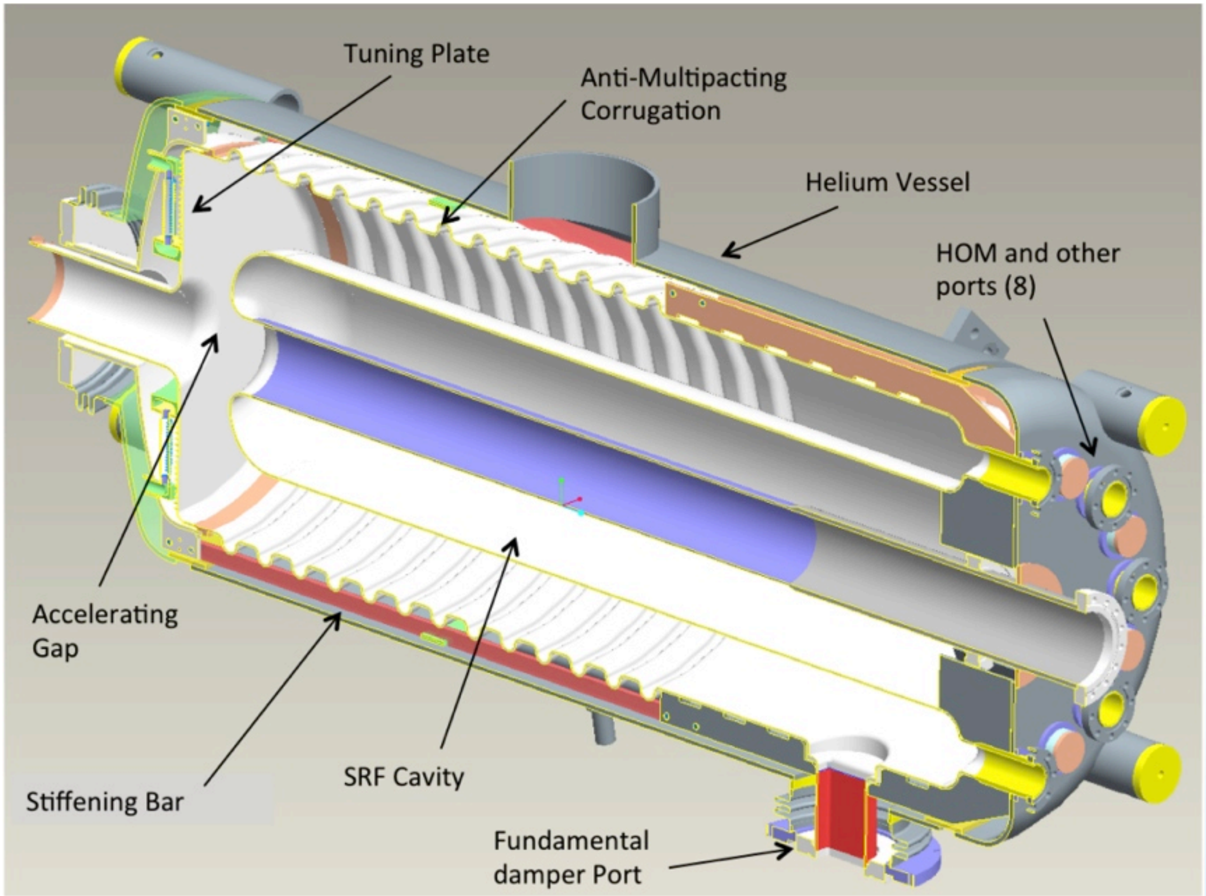
56 MHz cavity



- The purpose of this Quarter Wave Resonator (QWR) is to provide a larger RF bucket (5 times larger than that of 197 MHz cavities) for ions, which should result in higher luminosity of RHIC by: direct adiabatic capture from 28 MHz system, better preservation of longitudinal emittance, elimination beam spillage in satellite buckets, improving luminosity by allowing shorter beta function at the IP.
- This is a "storage" cavity, that is it does not have large tuning range to follow the large frequency change during acceleration from injection energy to energy of experiment and is turned on only after that for re-bucketing.
- One 56 MHz cavity will serve both RHIC rings. It will be the first superconducting RF system in RHIC.

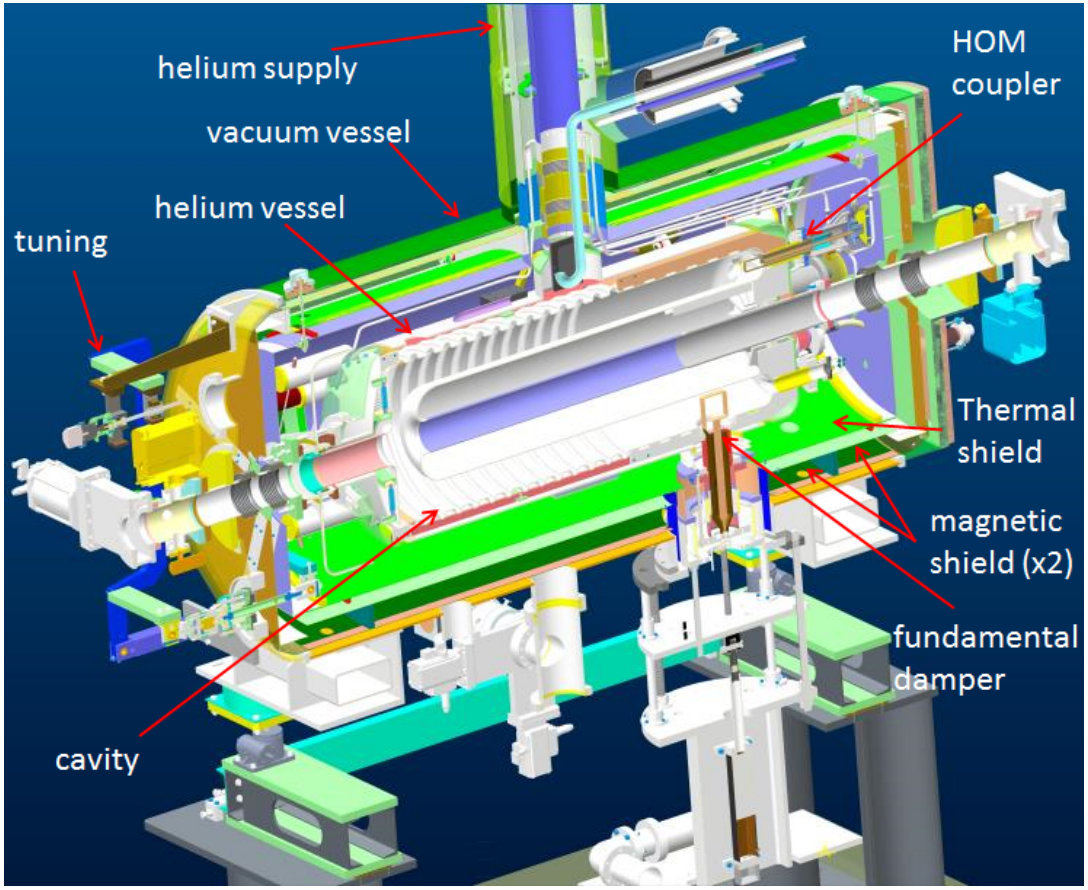
V_{acc}	2.0 MV
Stored energy	140 J
R/Q	80.5 Ohm
Geometry factor	33.5 Ohm
Operating temperature	4.4 K
Q_0 at low fields (assuming R_{res} = 10 nOhm)	3.0×10^9
Q_0 at 2 MV	2.4×10^9
P_{cav} at 2 MV	20.7 W
Q_L	4×10^7
Available RF power	1 kW
Coarse tuning range	25.5 kHz
Coarse tuning speed	3.7 kHz/s
Tuning sensitivity (stepper motor)	17 kHz/mm
Fine tuning range	60 Hz
Tuning sensitivity (piezo)	0.06 Hz/V
LF detuning at 2 MV	-132 Hz
Frequency sensitivity to He bath pressure	0.282 Hz/mbar
Peak detuning due to microphonic noise	1 Hz

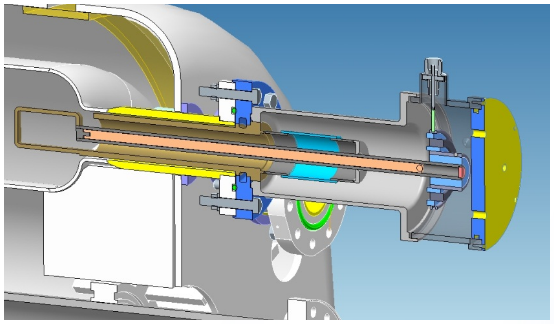
Cavity design



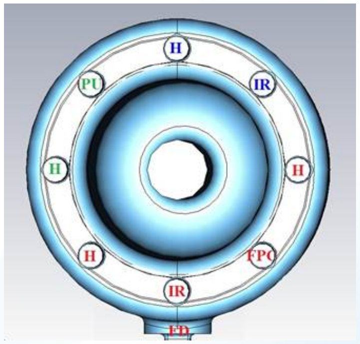
- The cavity is tuned to 720th harmonic of the RHIC revolution frequency.
- It is a beam driven cavity. However, there will be a 1 kW RF amplifier. The amplifier will serve to: achieve required amplitude and phase stability and provide conditioning capability.
- At the energy of experiment, first the fundamental damper will be withdrawn and then the cavity frequency will be tuned (approaching from below the beam harmonic) to achieve the operating voltage of 2.0 MV.
- The cavity is mechanically rigid: its first mechanical mode frequency is 98.5 Hz. We expect very little perturbation due to microphonic noise.

Cryomodule design features



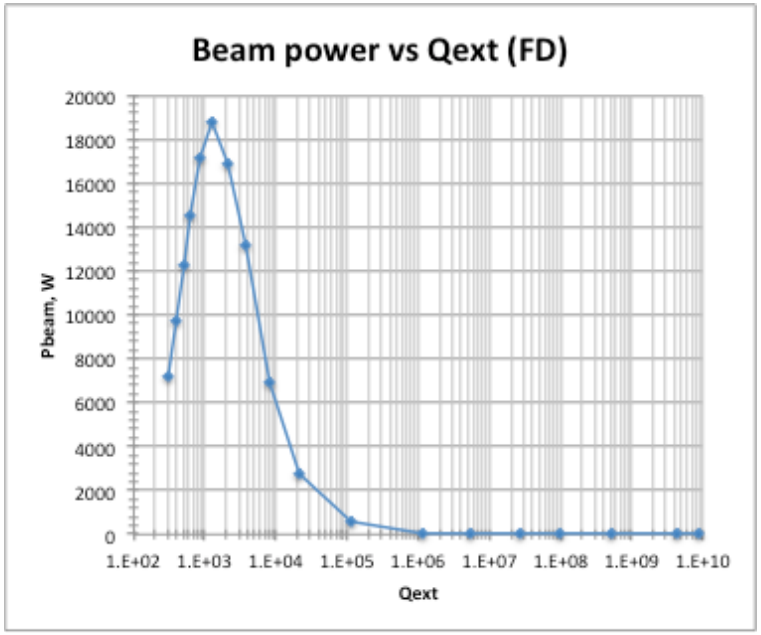


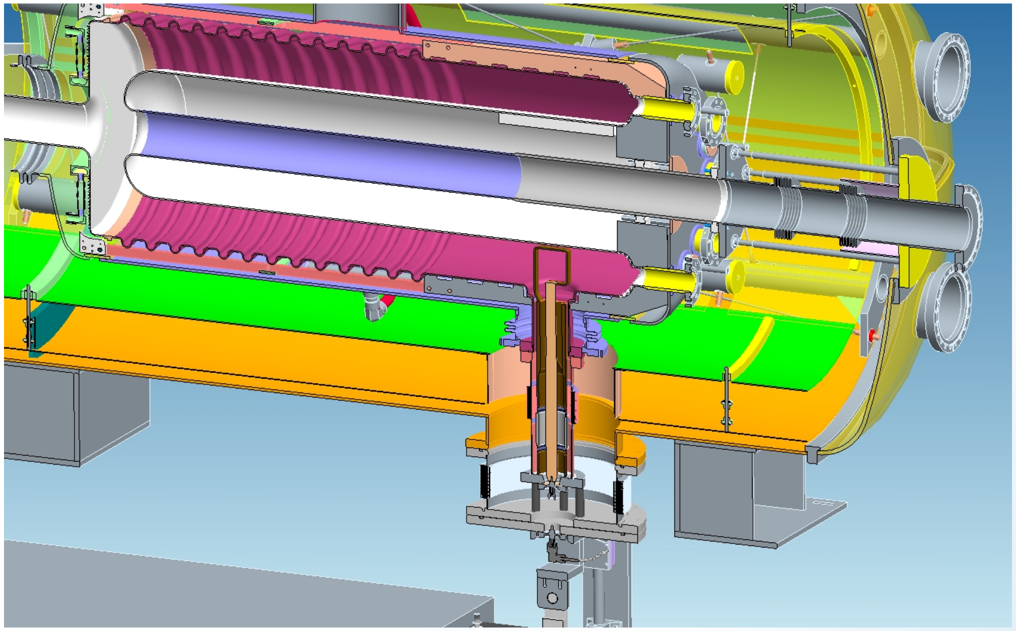
- A prototype HOM coupler has been fabricated at JLab, installed on the cavity.
- Production couplers are on order from Niowave.
- Expect delivery by the end of the month.
- We are going ahead with the cryomodule assembly using only one HOM coupler



- A coarse (stepper motor) mechanical tuner provides +/- 25 kHz tuning range. A piezo tuner will be employed to compensate any fast frequency changes.
- High degree of higher order mode (HOM) damping is provided by four dampers asymmetrically placed at the “short” end of the cavity.
- Fundamental mode Damper (FD) reduces the cavity fundamental mode *Q* to ~300 during beam injection and acceleration.

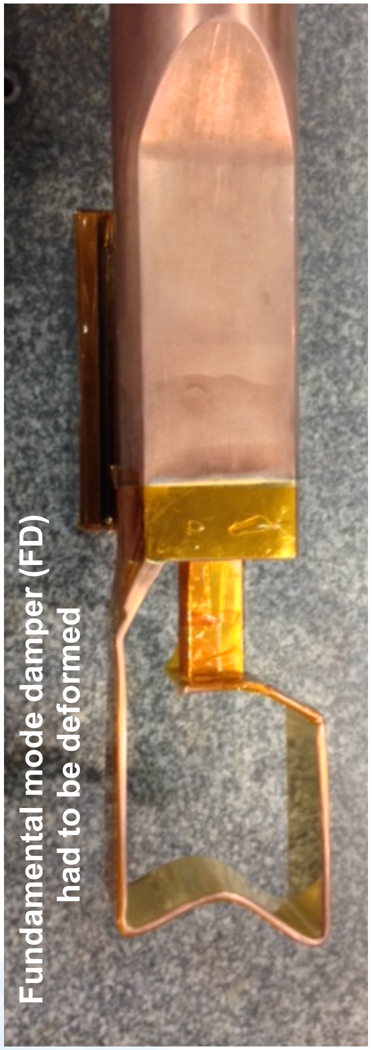
Fundamental mode Damper

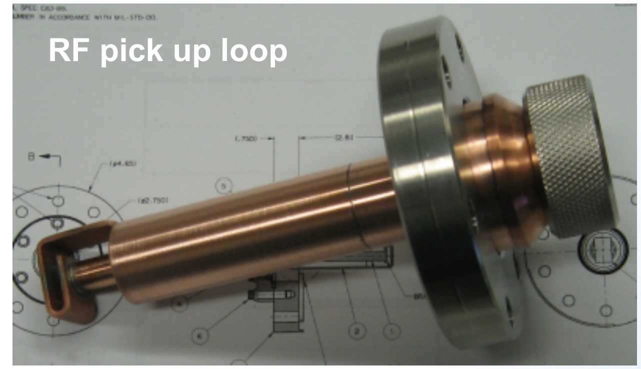


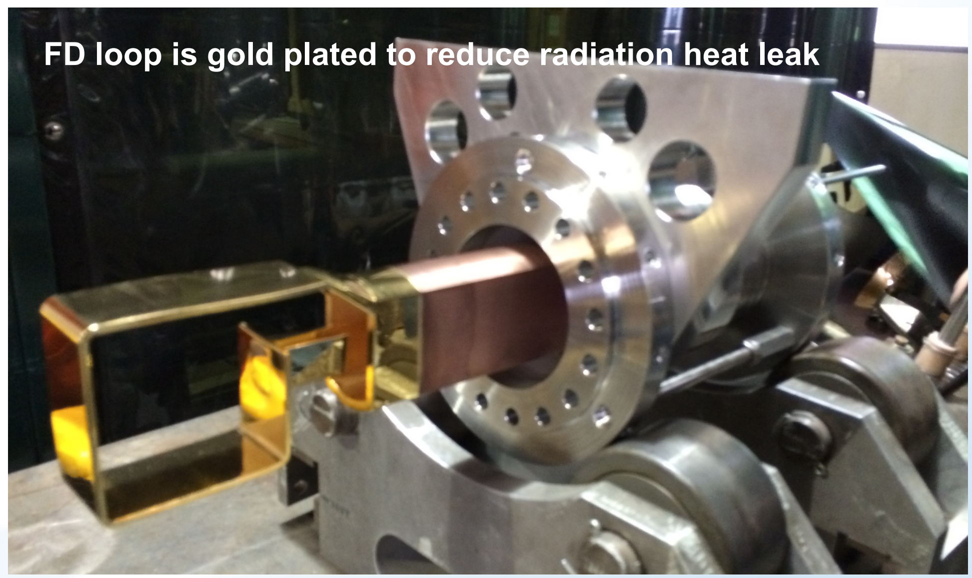


- FD is a unique component of the 56 MHz cavity. It will be inserted during the acceleration and retracted at store.
- Heavy damping (Q_{load} = 300) makes the cavity “invisible” (= low impedance) to the beam during acceleration, therefore no large frequency tuning range is needed. It is moved between two positions by a stepper motors outside of the cryostat.
- At a total beam current of 0.6 A, RF power extracted via FD is ~7 kW in fully inserted position. During motion the power will peak at about 19 kW and then quickly decrease to a very low value.
- FD, fundamental power coupler and RF pick-up probe are fabricated by MPF.

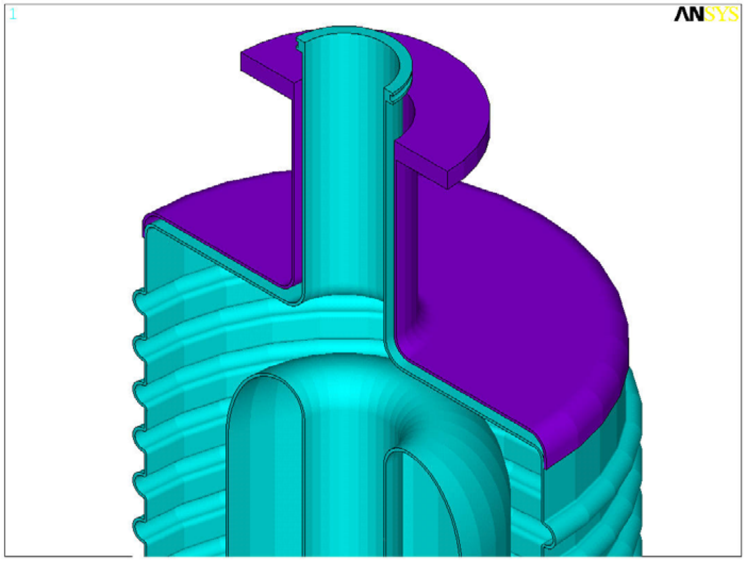
Components: FD, FPC, RF pick up

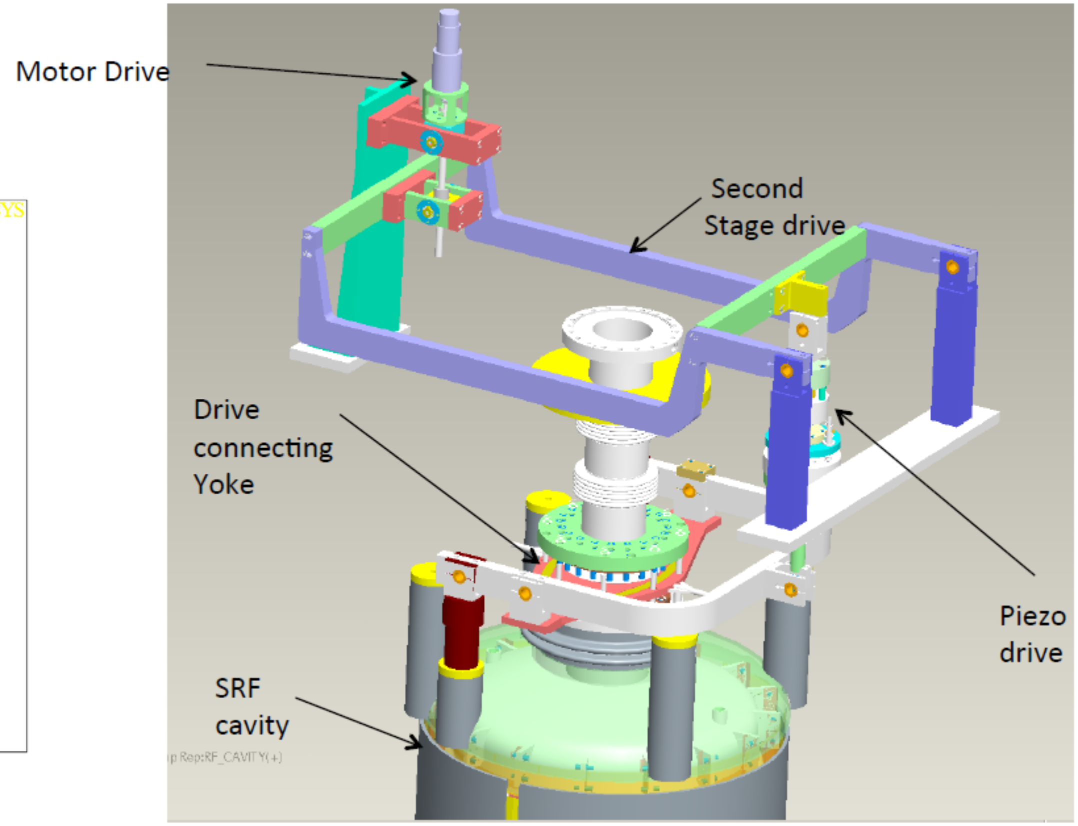






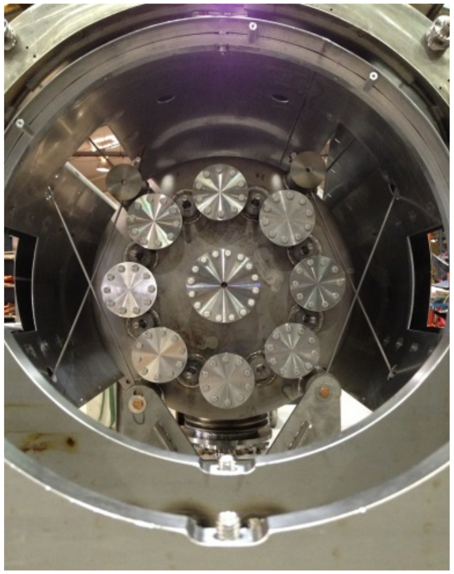
Frequency tuner

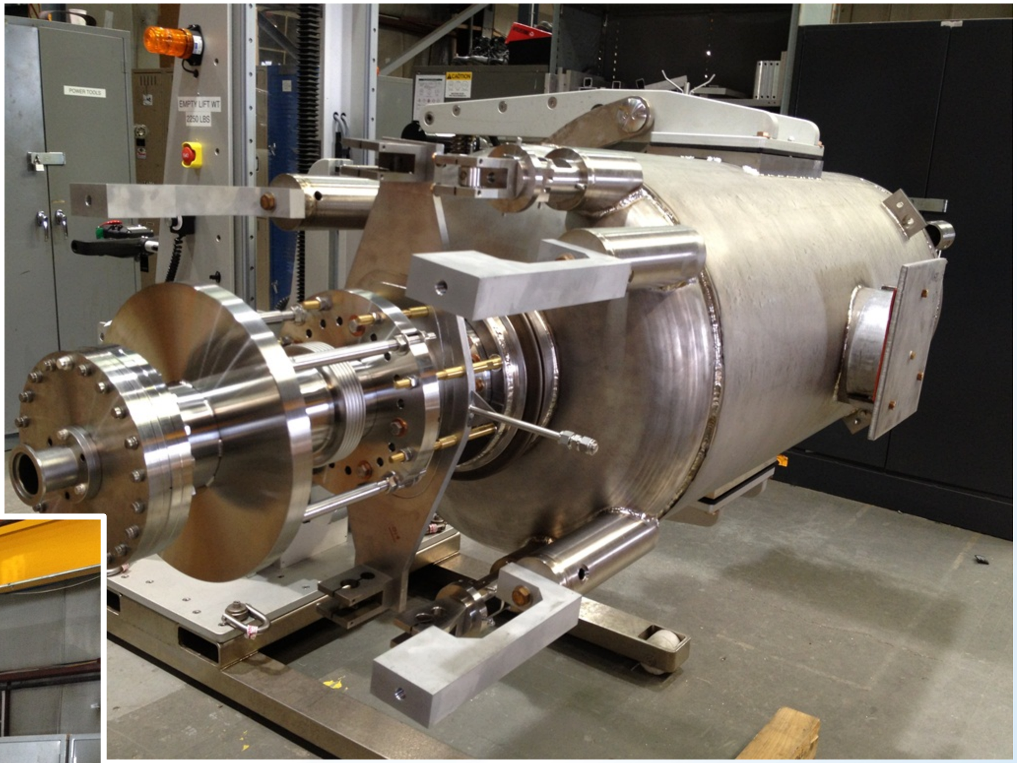


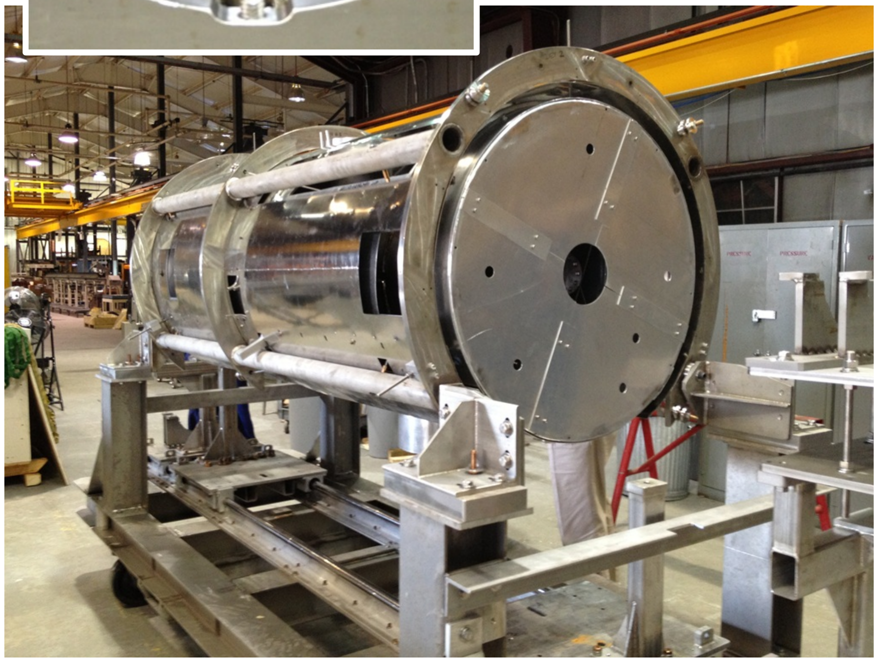


- Mechanical tuning of the RF cavity resonance frequency will be achieved by physically pushing or pulling the upper part of the SRF cavity (tuning plate) to change the gap.
- A tuning mechanism mounted on the helium vessel will provide both fast and slow tuning for the SRF cavity to change its fundamental resonance frequency.
- The tuner plate is an internal structure of the RF cavity vessel. A crown head is welded over the tuner plate to take helium pressure. The tuner plate is free from helium and vacuum pressure.
- Total leverage ratio is 24.88.

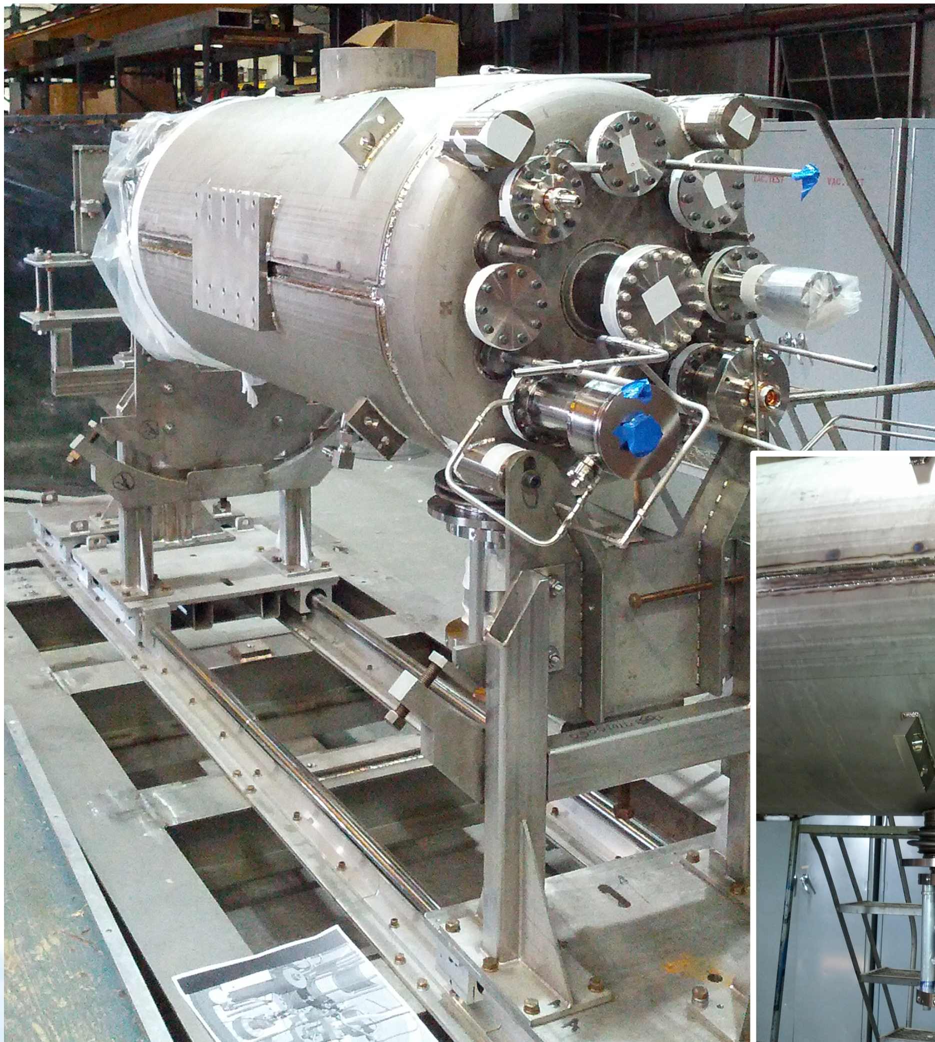
Mock-up cryomodule assembly in 905

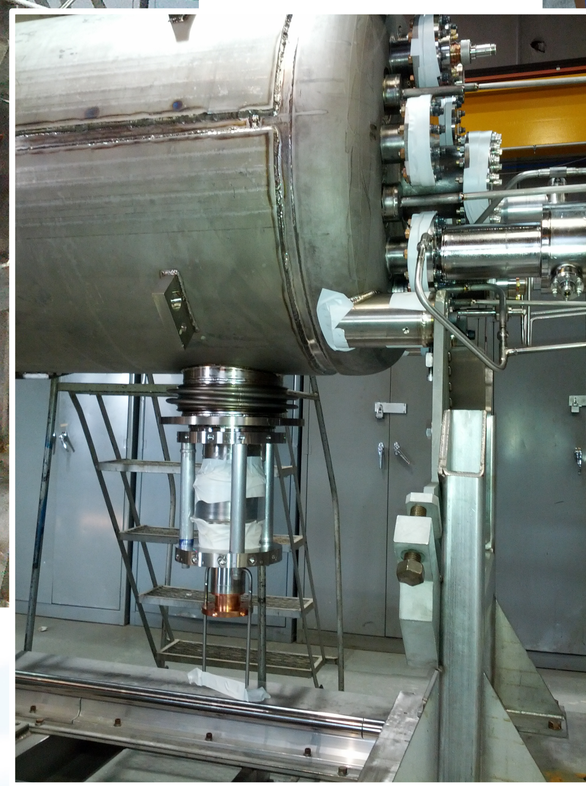


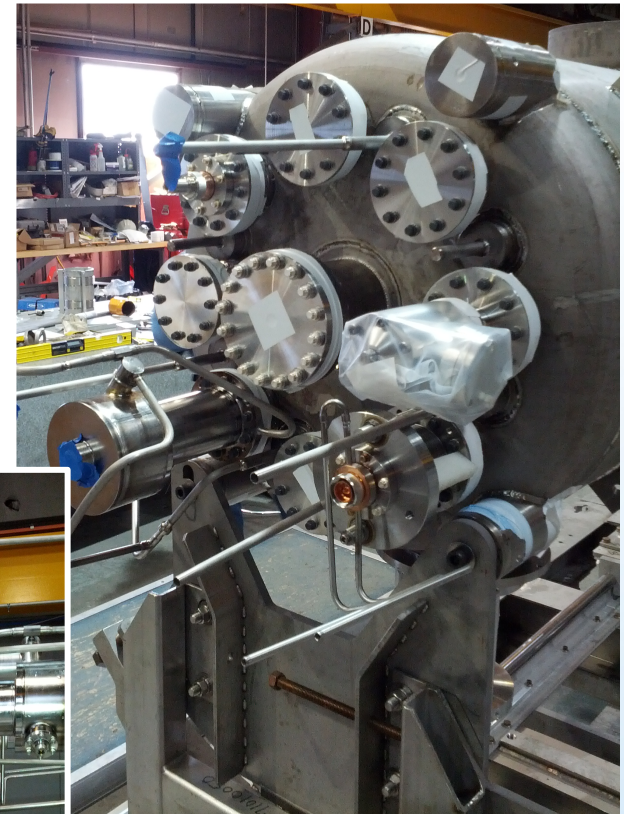




Cavity string assembly status

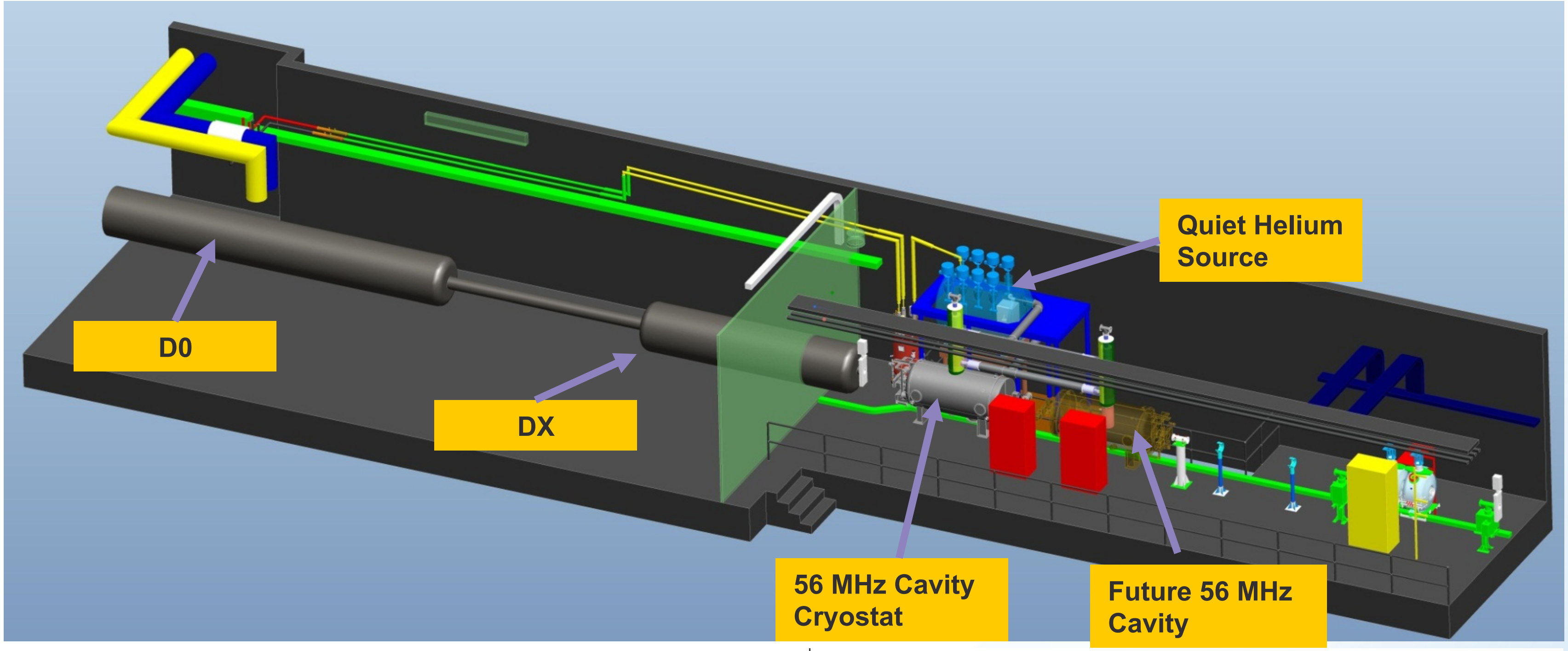


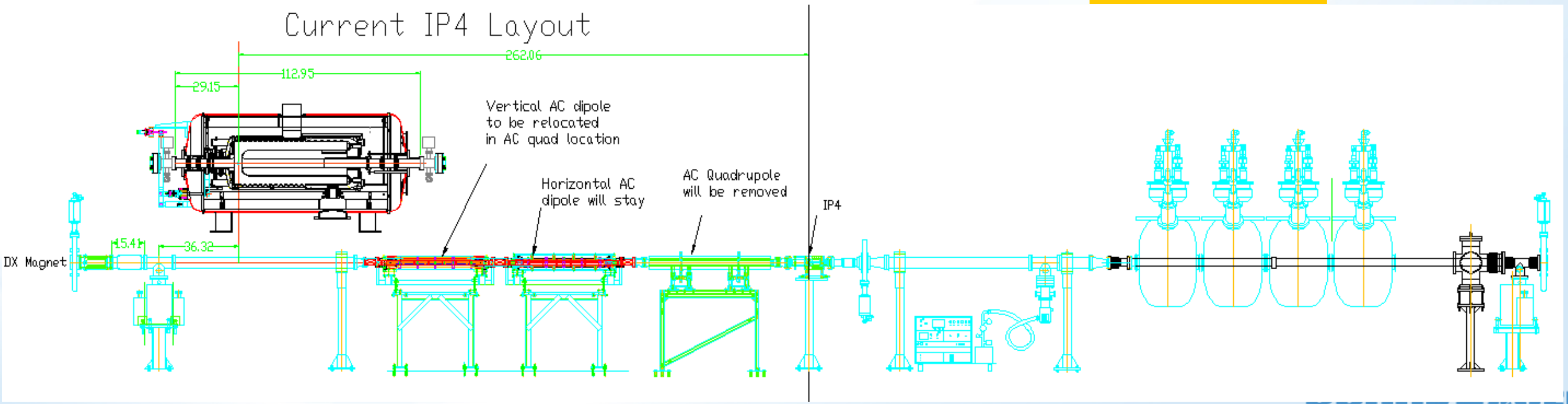




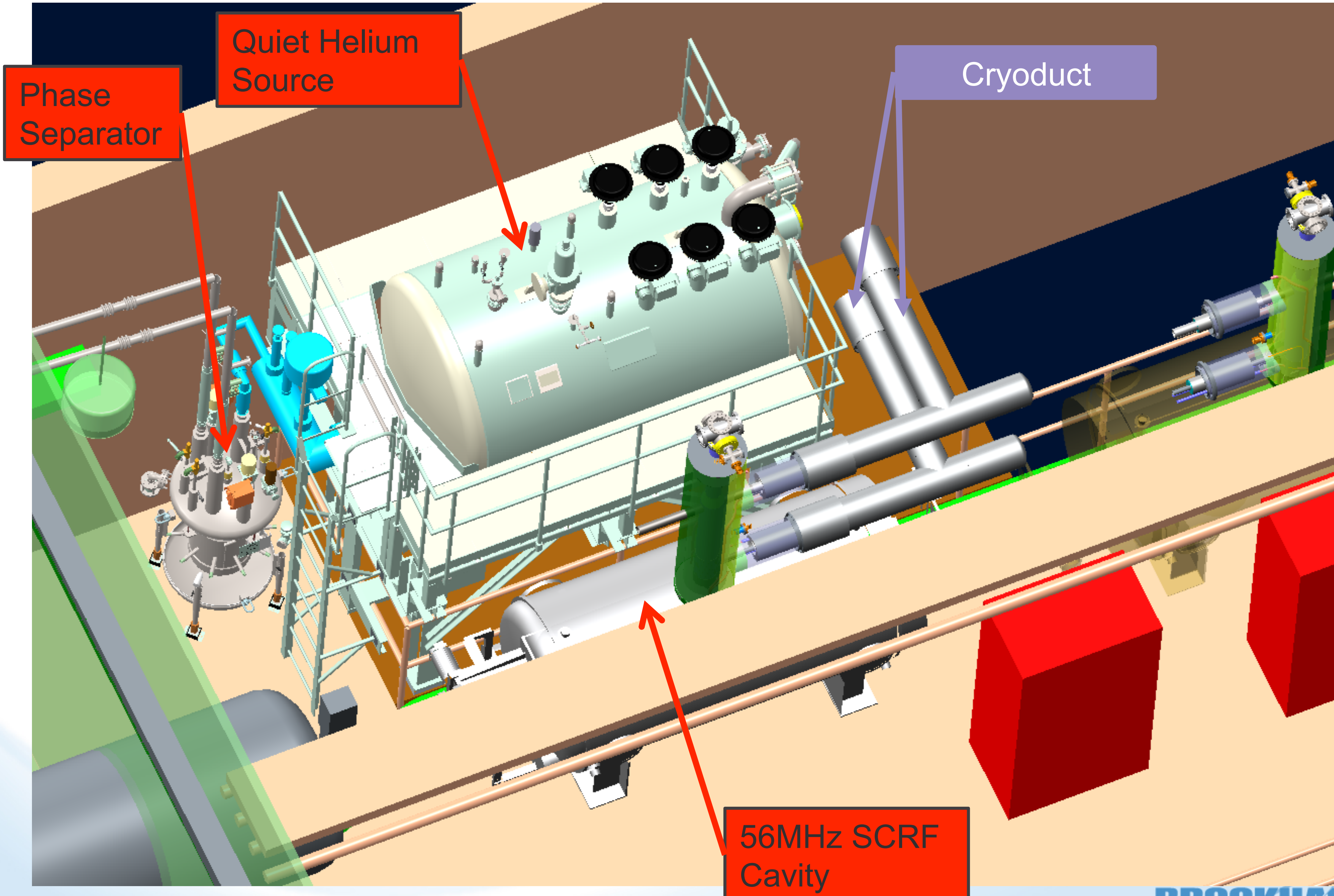
Installation in RHIC

56 MHz cavity will be installed in the IP4 area





System layout in IP4



RF system

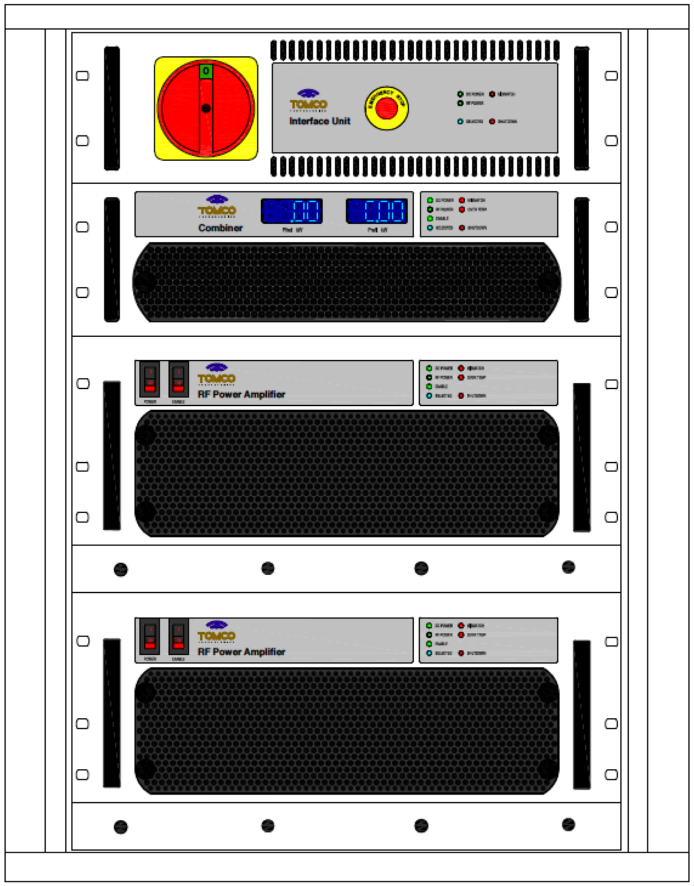
- The 56 MHz SRF cavity is a beam driven cavity. RF system needs power only to fight microphonics detuning (1 Hz peak):

$$P_{forw}^{pk} = \frac{V_c^2}{R/Q} \cdot Q_{ext} \cdot \left(\frac{\delta\omega_m}{\omega}\right)^2 = 0.63 \text{ kW}$$

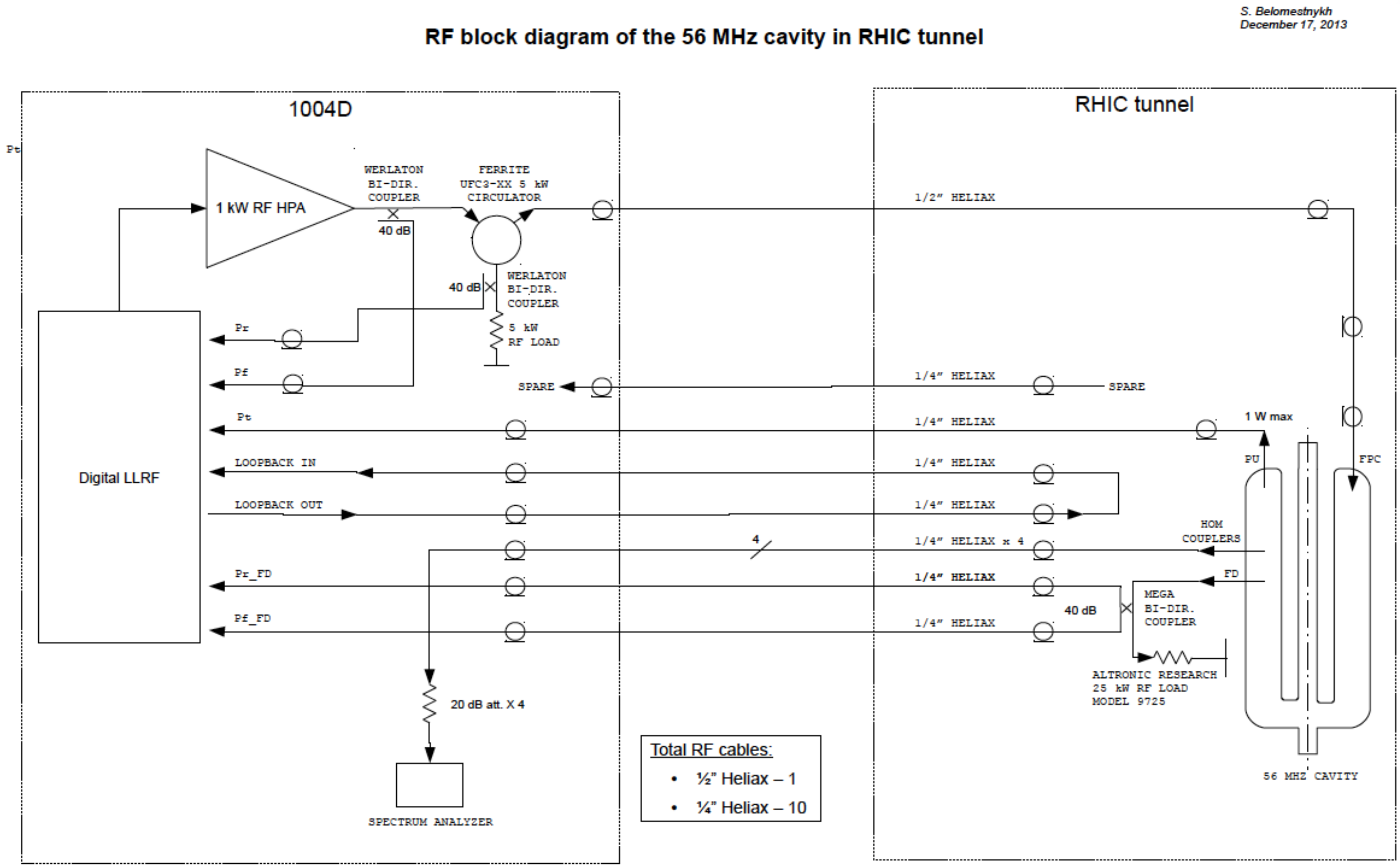
- However, the power coming back from the cavity to RF amplifier is

$$P_{refl}^{pk} = \frac{V_c^2}{R/Q \cdot Q_{ext}}\left[1 + \left(Q_{ext} \cdot \frac{\delta\omega_m}{\omega}\right)^2\right] = 1.88 \text{ kW}$$

- 1 kW RF power amplifier was purchased from AR. Its initial testing was OK, but it failed recently during re-testing and is back at the vendor for repairs.
- A spare amplifier was ordered from TOMCO. This amplifier we will use in operation.

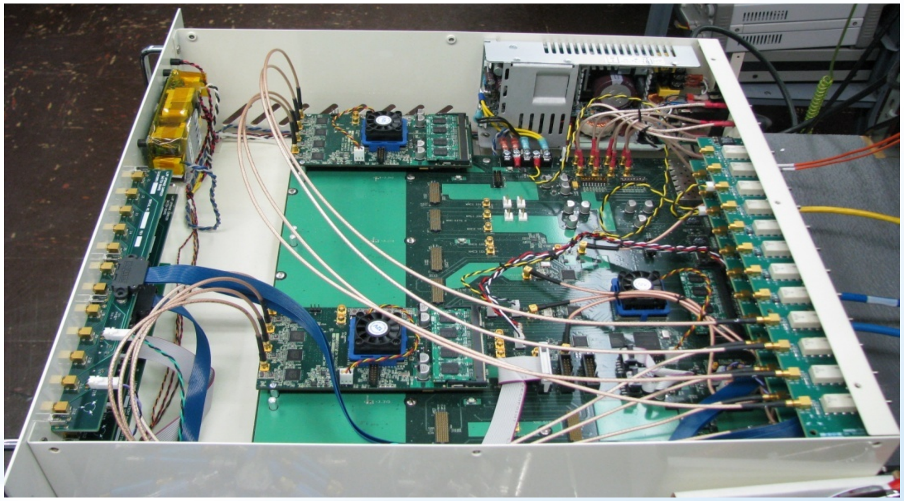


RF block diagram

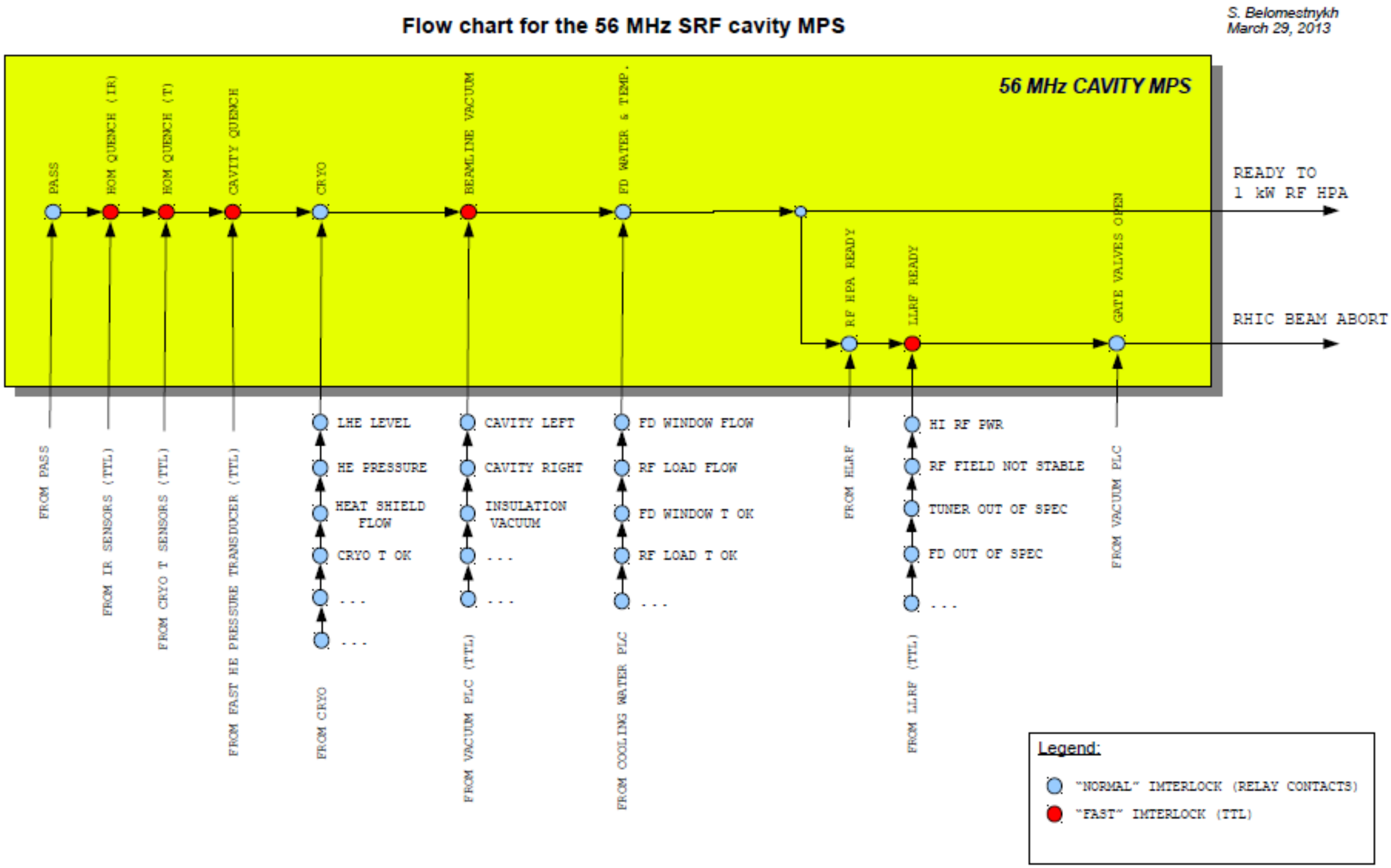


LLRF control

- Cavity field control objectives
  - Amplitude and phase: 1E-4 rms (“AC” variation only, absolute “DC” voltage and phase determined by beam and cavity detuning).
- Adiabatic turn on under control of state machine slowly pushing cavity frequency toward beam frequency, via stepper tuner.
- “Slow” feedback via piezo tuner for control of cavity impedance to maintain nominal 2.0 MV on the gap.
- “Fast” feedback via LLRF drive and 1kW PA to compensate microphonic detuning, i.e. “AC” variations about the nominal 2.0 MV setpoint within a few hundred Hz modulation bandwidth.
- Cavity and machine protection.
- 56 MHz system is a variant of the recently developed generic LLRF Controller, currently being used at EBIS, AGS, RHIC and ERL.



Machine protection system



Off-normal events, consequences and actions

Event	Impact on cavity	Consequences	Sensors & signals
Cavity quench	Excessive heat dissipation	Helium bath pressure burst	Fast rise of the He bath pressure; Excessive 28 MHz RF power demand
HOM damper quench	Excessive heat dissipation	Elevated HOM damper temperature	IR & Temperature sensors
RF system trip	No RF power for field regulation	High amplitude/phase noise	LLRF or High power RF is not ready
Tuner malfunctioning	Cavity voltage out of spec	Cavity quench	“Tuner is out of spec” from LLRF
Cryogenic problem	Loss of He pressure/level control	High He pressure / low liquid He level	He pressure or LHe level are out of spec
Cavity/beam pipe vacuum leak	Poor vacuum	Numerous, depending on scenario	Signals from vacuum gauge and pump controllers
Insulation vacuum leak	High heat leak to LHe	High He pressure/low liquid level	He pressure or LHe level are out of spec
Multipacting	Excessive local heating	Vacuum spike, cavity quench, elevated temperature	Signals from vacuum gauge and pump controllers
FD malfunctioning	Excessive RF power	FD overheating	FD temperature sensors; High RF load power from LLRF
Beam dump	-	No beam induced voltage	“Beam dump” from RHIC Control System
Beam current too low	-	Not possible to maintain voltage	“Low beam current” from either RHIC Control System or LLRF

Reaction to all off-normal events should be:
- dump the beams in RHIC
- turn RF OFF
- detune the cavity to “home” position
- fully insert FD

Commissioning plan

1. Warm testing.
2. Pre-Ops.
3. Cold testing/commissioning.

Warm testing

- Network Analyzer measurement of the Fundamental mode Damper (FD) coupling, Q_L ~ 300, when FD is fully inserted.
- The cavity quality factor at RT is ≈ 3.6×10^3.
- Network Analyzer measurements:
  - Cavity frequency – nominal 56.201 MHz at RT, 56.299 MHz when cold;
  - Coarse (stepper motor) tuner range, ± 25 kHz;
  - The cavity must be deformed if not within the range;
  - Fine (piezo) tuner range of 60 Hz;
  - Calibrate RF signals at RT.

Pre-Ops

- MPS tested and configured properly.
- With RHIC at 40 K:
  - Can provide cold He gas for cavity cooling ;
  - Use FD to apply up to 1 kW RF for conditioning of multipacting – can reach about 17 kV.

Cold testing/commissioning

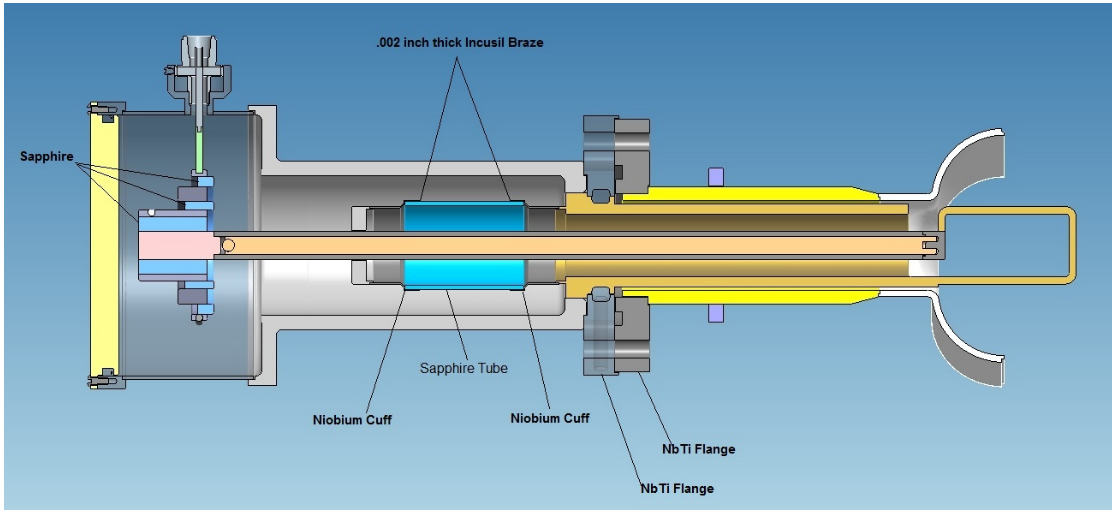
- RHIC at 4 K, about two days available during PS testing:
  - Finish MP conditioning;
  - Signal calibration, preliminary LLRF set up, verify LLRF protection functions;
  - Check cavity performance (Q *vs.* V);
  - Verify tuner operation;
  - Characterize microphonics;
  - Measure HOM spectrum.
- Store commissioning:
  - Can continue testing as far as the cavity frequency is offset from the beam frequency;
  - Observe/measure beam reaction on FD withdrawal, measure HOM spectrum excited by beam;
  - Verify tuner control and cavity voltage response;
  - Verify proper system response when beam is dumped;
  - Characterize AC coupled IQ loop performance at very low cavity voltage, set up gains, etc.

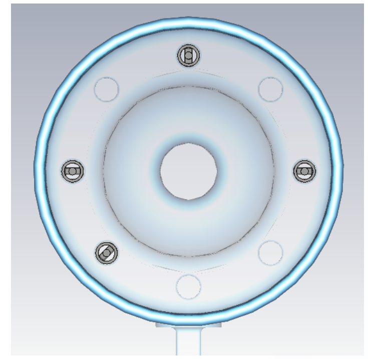
Summary

- 56 MHz cavity cryomodule assembly is progressing towards installation in RHIC.
- The ancillary components (FPC, FD, one HOM coupler, RF pick up) are attached to the cavity.
- The cavity string assembly in the clean room will be complete next week, followed by the cryomodule assembly.
- All sub-systems are on track to be ready for the cavity installation.

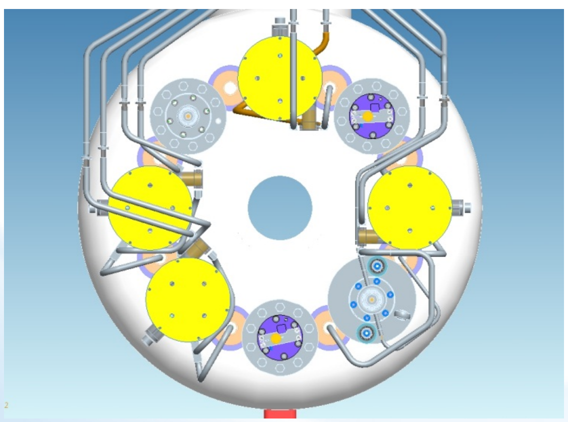
Backup slides

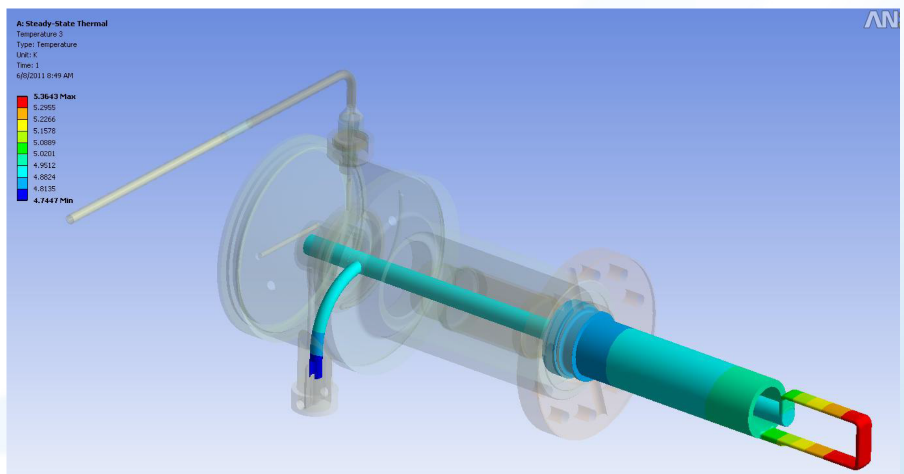
HOM coupler = coupling loop + filter



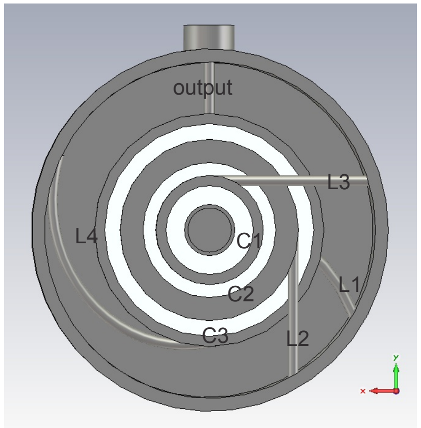


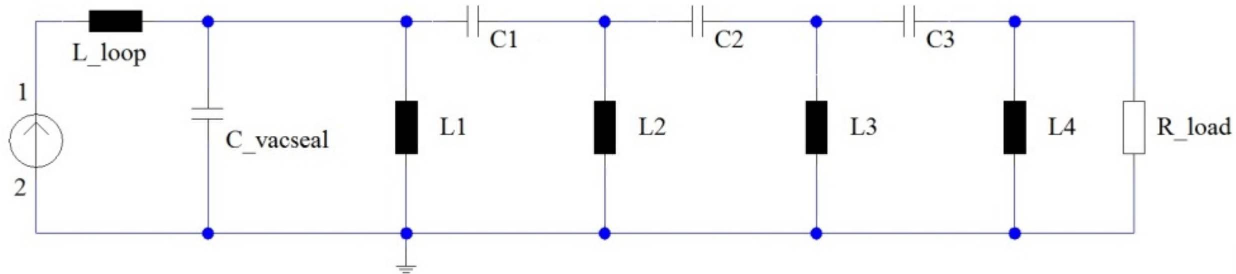
- Optimization of damping for all HOM modes up to 1 GHz, resulted in 4 HOM couplers.
- The couplers are inserted in an asymmetric configuration, which ensures that all modes are damped adequately.
- The NbTi flange will be cooled with helium.
- A high RRR copper rod inside the center conductor improves cooling of the loop. It is LHe-cooled.

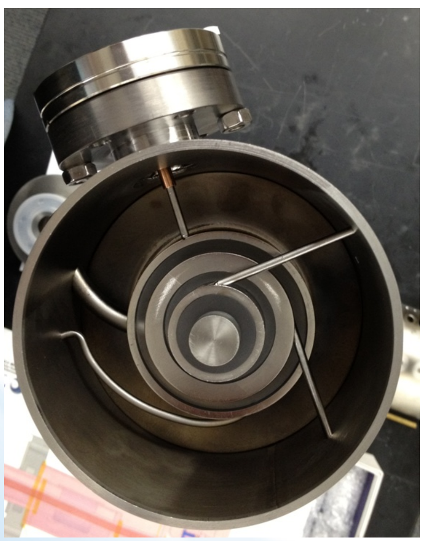




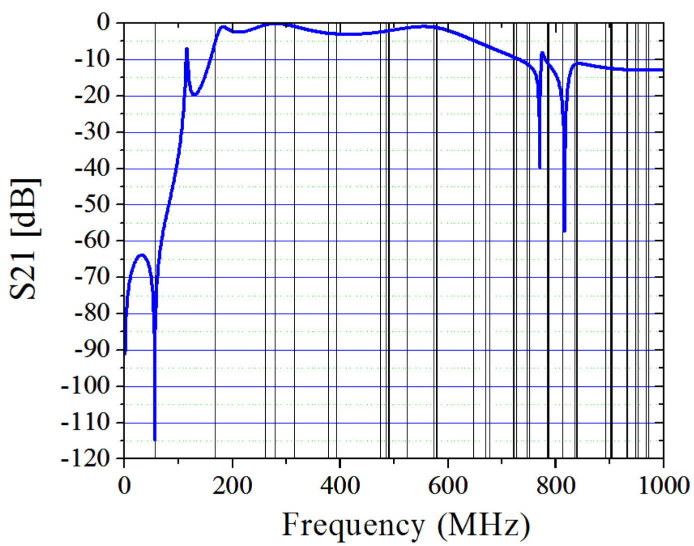
HOM filter

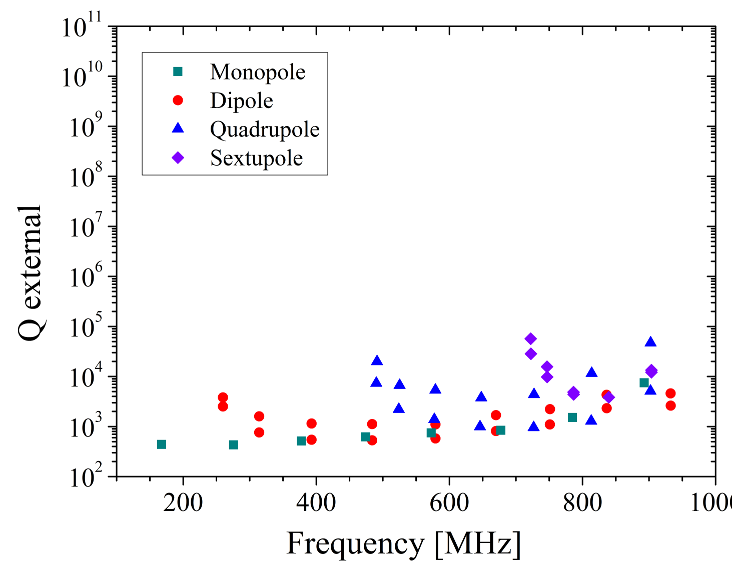






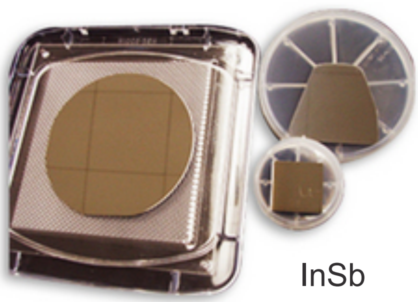
- A Chebyshev-type filter provides -110 dB attenuation at 56.3 MHz, which limits the output power of the fundamental mode to less than 1 mW.
- The total power of the HOM modes excited by the beam in the 56 MHz SRF cavity is ~1.1 W during operation, both rings are included. With the filter installed, the HOM total power output is ~0.33 W/damper.
- Prototype coupler is being fabricated at JLab, production units are on order from Niowave.



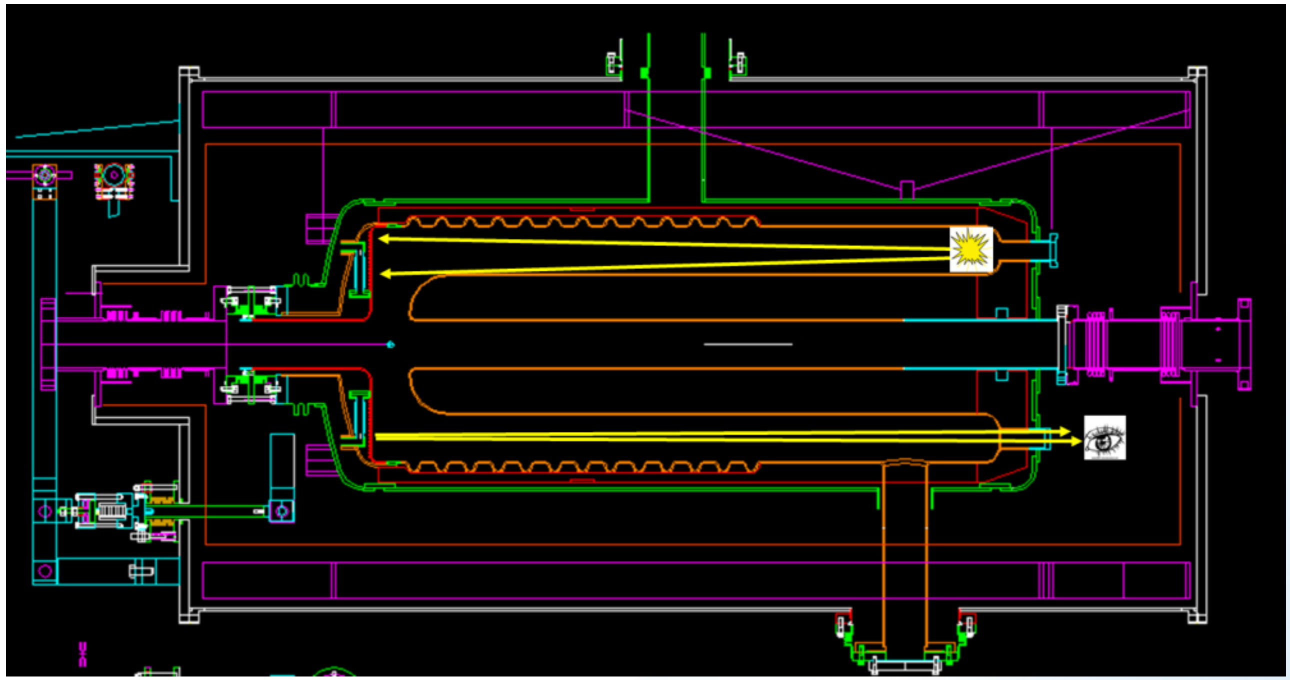


IR sensors for quench detection

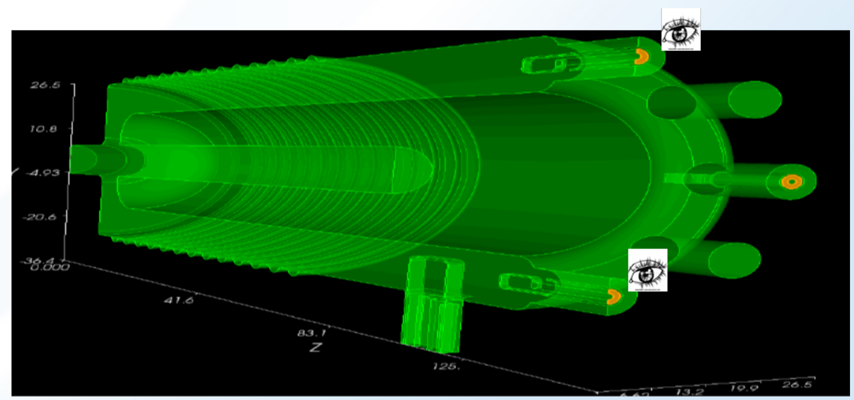
MCT
(HgCdTe)



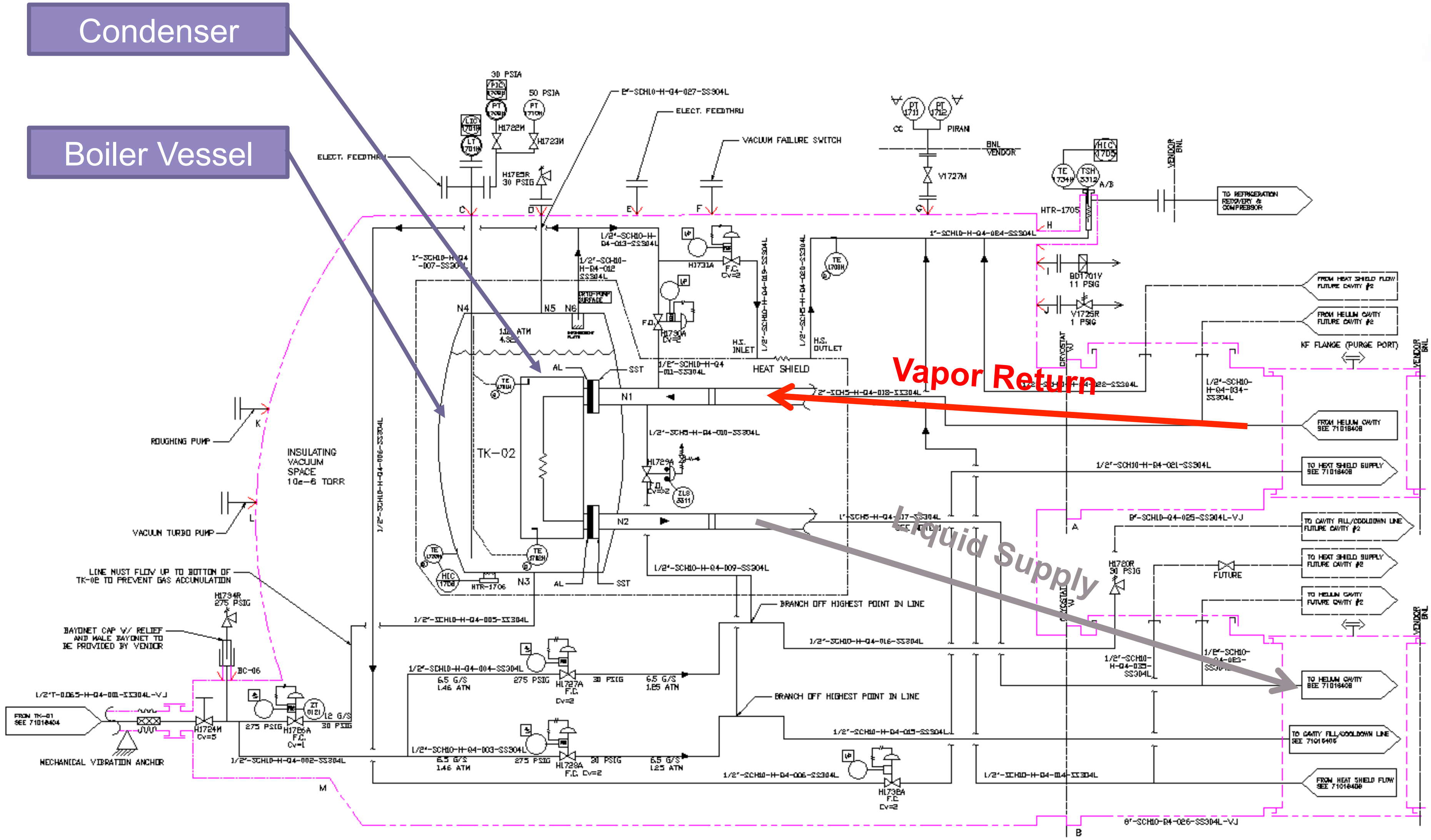
InSb



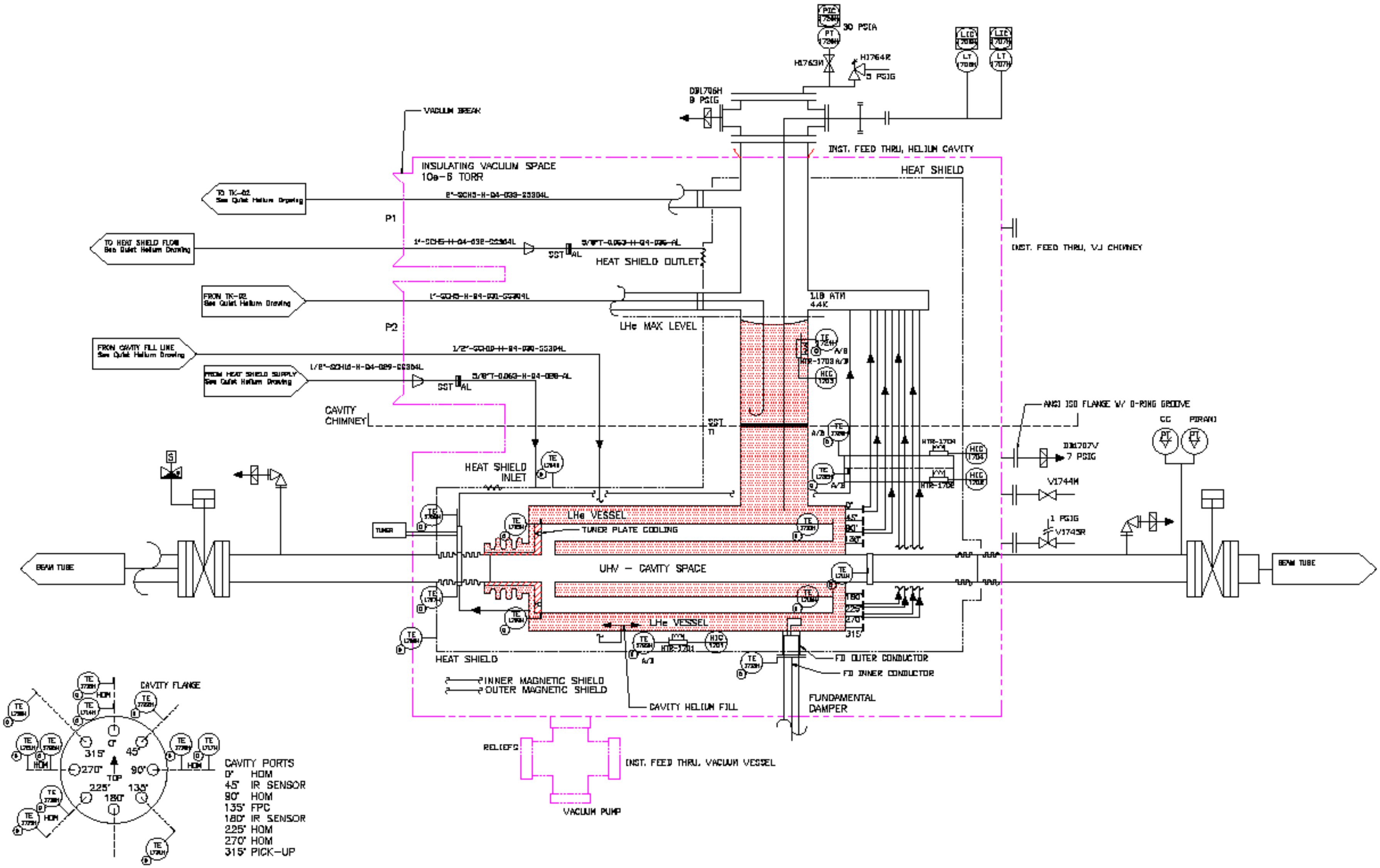
- Purpose: detect thermal radiation from a quench event on the HOM dampers.
- Sensors look into the cavity from end ports and detect IR radiation reflected from the hotspot
  - Nb highly reflective at IR wavelengths
- Two units on 2 end ports. Each unit includes, mounted on a ZnSe window:
  - a detector, HgCdTe or InSb
  - a pulsable thermal source for testing: test one by flashing the source on the other



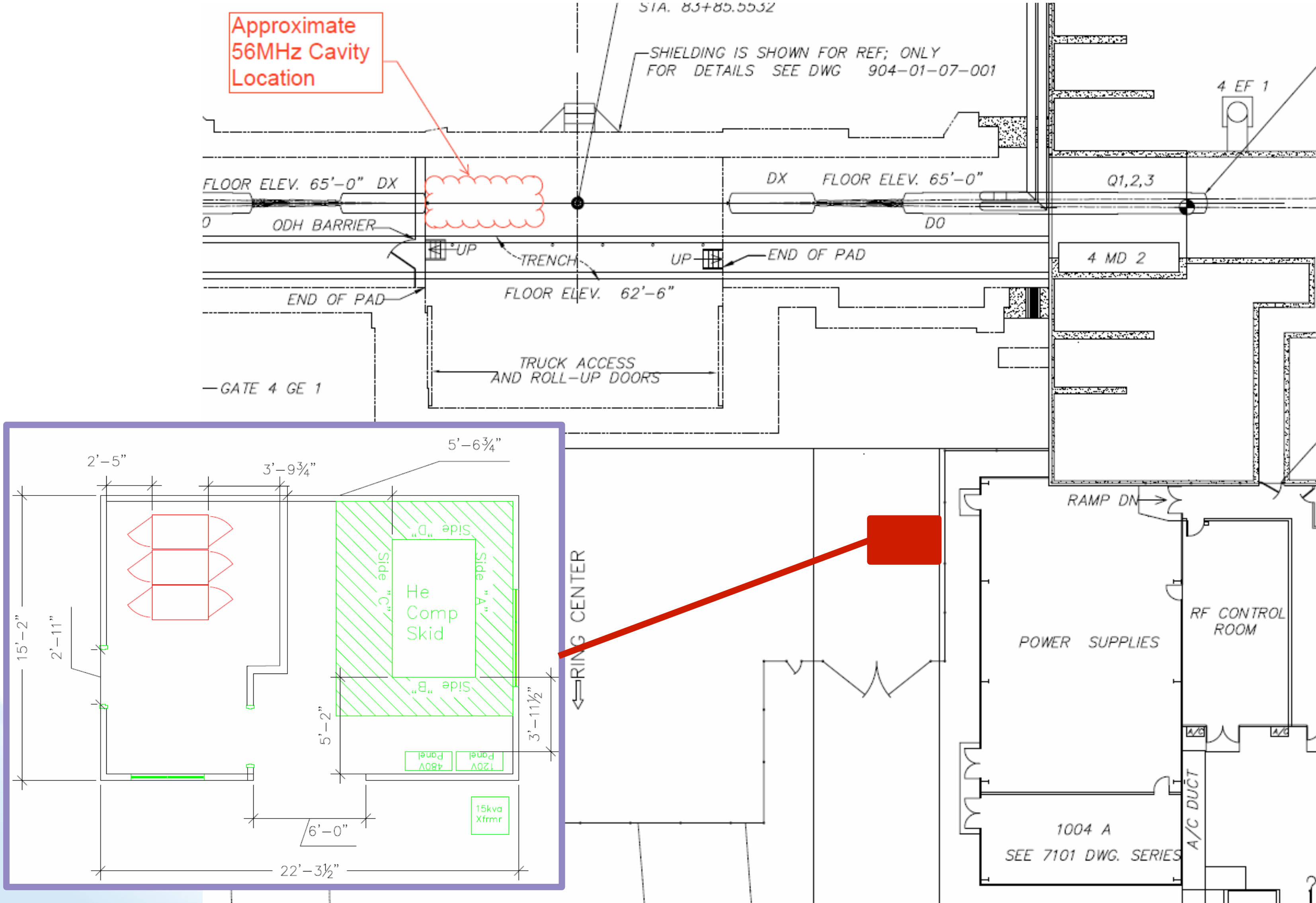
QHS P&ID – Interface review



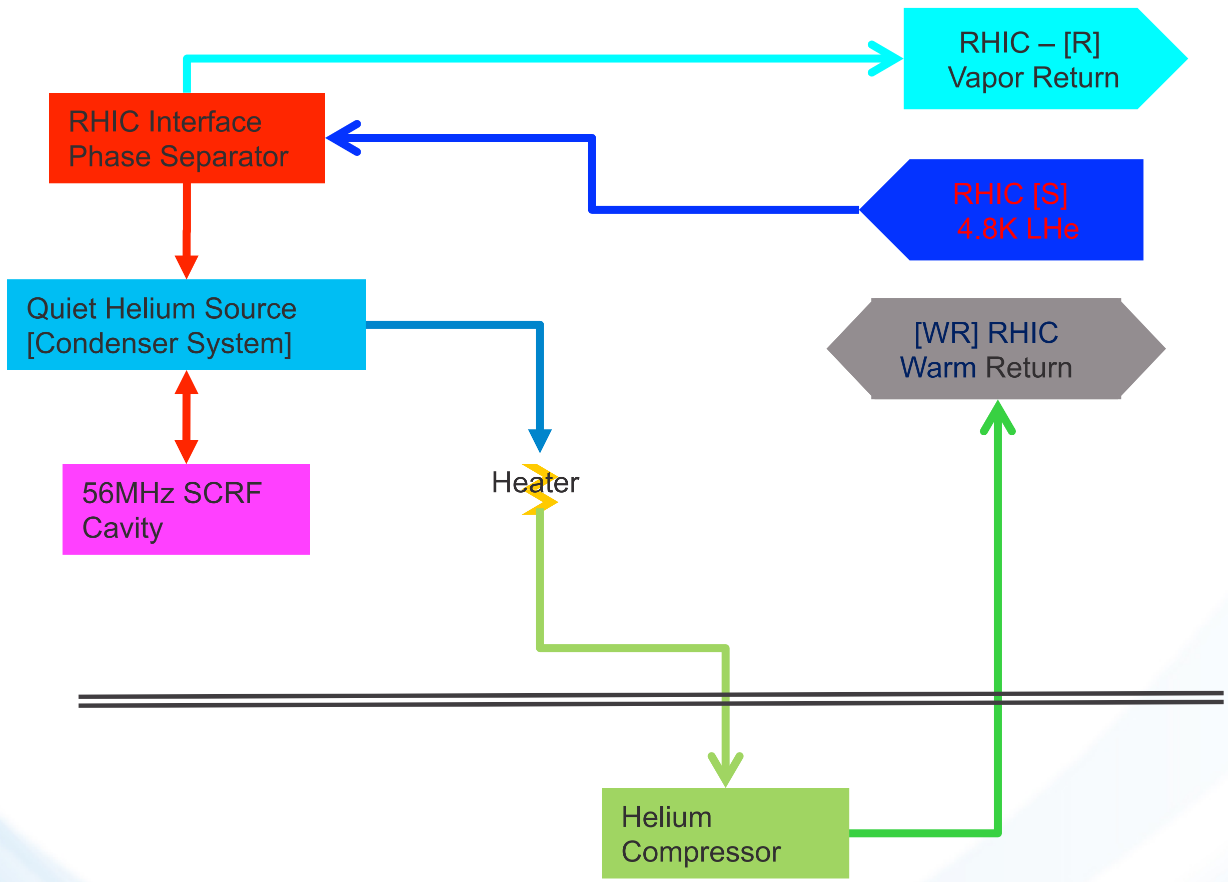
56 MHz SRF Cavity Cryomodule P&ID



Small helium compressor location



Cryogenic system at IP4



- **Condenser/Boiler**
  - ✓ Condenses the boil-off vapor
  - ✓ Condenser/Boiler design heat load is 200 W
  - ✓ Heat transfer surface area 39.5 m^2 (condenser) & 33 m^2 (boiler)
  - ✓ Condenser side is operated at 4.4 K and 1.2 bar
  - ✓ Boiler side is operated at 4.3 K and 1.09 bar
- **Condenser Load Heater**
  - ✓ A 50 W load heater is mounted in the helium bath to balance the effect of dynamic heat load to maintain a constant heat load on condenser side, and therefore a constant pressure.
- **HOM Cooling Loop**
  - ✓ Each HOM is cooled by a helium siphon loop – liquid helium enters HOM and outgoing tube is heated to induce helium flow and remove the heat generated within the HOM.

IP4 Layout (vacuum system components)